Assimilating Data into a Circulation Model

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LONG-TERM GOALS

The long-term goal of this study is to build an integrated circulation observation/prediction system where a variety of remote and in situ field observations can be assimilated into a numerical model to provide near real-time nowcasting and forecasting capabilities in the nearshore.

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14. ABSTRACT
The long-term goal of this study is to build an integrated circulation observation/prediction system where a variety of remote and in situ field observations can be assimilated into a numerical model to provide near real-time nowcasting and forecasting capabilities in the nearshore.

15. SUBJECT TERMS

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OBJECTIVES

Our objective is to construct an integrated modeling capability that will rely on advancements in both models and spatially dense measurements of nearshore currents. The system consists of an existing numerical model of the depth- and phase-averaged equations of motion governing the temporal and spatial evolution of the nearshore circulation (Özkan-Haller and Kirby, 1999), and will utilize observations of surface current patterns obtained using Particle Image Velocimetry (PIV) techniques applied to a video system (PI's Lippmann and Holland) as well as other remotely obtained data such as surf zone width or proxies for radiation stress gradients (PI Holman). Our focus is on a thorough understanding of the circulation field over complex bathymetry, and testing of the modeling scheme as part of the Nearshore Canyon Experiment (NCEX) during the fall of 2003 (see http://science.whoi.edu/users/pvlab/NCEX/index.html). Our specific objectives are to:

- Adapt an existing nearshore circulation model based on the depth- and phase-averaged nonlinear equations of motions (Özkan-Haller and Kirby, 1999) to incorporate observations of currents. Test resulting model with synthetic and existing data.

- Test our model scheme with field data obtained by collaborating groups as part of NCEX. This work will began on-site during the experiment, and has continued in the subsequent year following its conclusion.

- Develop and implement methods of data assimilation that will aid in the incorporation of non-traditional measurements that can be obtained from surf zone video observations, such as surf zone width and energy dissipation.

APPROACH

Our approach is centered around utilizing state-of-the-art wave and circulation models to predict the wave and circulation field on complex bathymetry given estimates of offshore wave conditions. In situations where the system proves sensitive to input conditions (such as knowledge about the bathymetry or offshore wave field to a degree of accuracy that cannot be obtained with traditional methods) our approach involves taking advantage of spatially dense observations of the nearshore system obtained using video-based methods to augment the model predictions. This can be formally achieved with the use of data assimilation techniques, either through computationally efficient sequential estimators (popular in atmospheric predictions) or computationally expensive adjoints methods (used in larger scale oceanography). Our efforts are centered around the Nearshore Canyon experiment (NCEX) which provides us with a complex situation where we can test our wave and circulation prediction system.

WORK COMPLETED

The Nearshore Canyon experiment (NCEX) took place in the fall of 2004. We have contributed to the data collection by working closely with the groups of Drs. Lippmann and Holman. The graduate student involved in this project (Mr. Joseph Long) spent 3 months on site at NCEX and actively aided in the collection of twice-weekly bathymetry data and nearly continuous video data. During the experiment we also worked on generating merged bathymetry files that would incorporate the collected nearshore bathymetry data with the historically available canyon bathymetry. We further

carried out simulations for the wave field and the resulting circulation on site. Comparisons with preliminary observations on site were encouraging. Upon conclusion of the field experiment we have worked on comparisons between circulation predictions and video observations for several days during which multiple rip currents were observed around the Blacks Beach site. Our predictions of the rip current locations and strength exhibited substantial skill. We subsequently analyzed the dynamic balances that lead to the occurrence of a rip current at a given location.

RESULTS

We have carried out simulations of the wave field in the NCEX region utilizing several wave propagation models (REF/DIF 1, STWAVE, SWAN, and REF/DIF S). Comparisons of predicted wave angle of incidence and surf zone width are being carried out with estimates obtained by Holman and his group using Argus images of the region.We have so far concentrated on simulations for two days during NCEX (October 10 and October 31, 2003) during which strong rip currents were observed. As an example, Figure 1 shows the predicted spectral transformation over the complex bathymetry of the canyons for October 10, 2003 at NCEX. The model is initiated using an offshore spectrum measured at the Torrey Pines buoy (provided by Dr. Bill O'Reilly). The spectrum consists of swell approaching from the northwest and longer period swell from the southwest. As the waves propagate into shallower water the two peaks refract strongly. By the time they reach the Scripps canyon both peaks have merged into one broad peak that is now approaching from the south. We will see later that these waves force a northward longshore current immediately shoreward of the "heel" of the Scripps canyon.

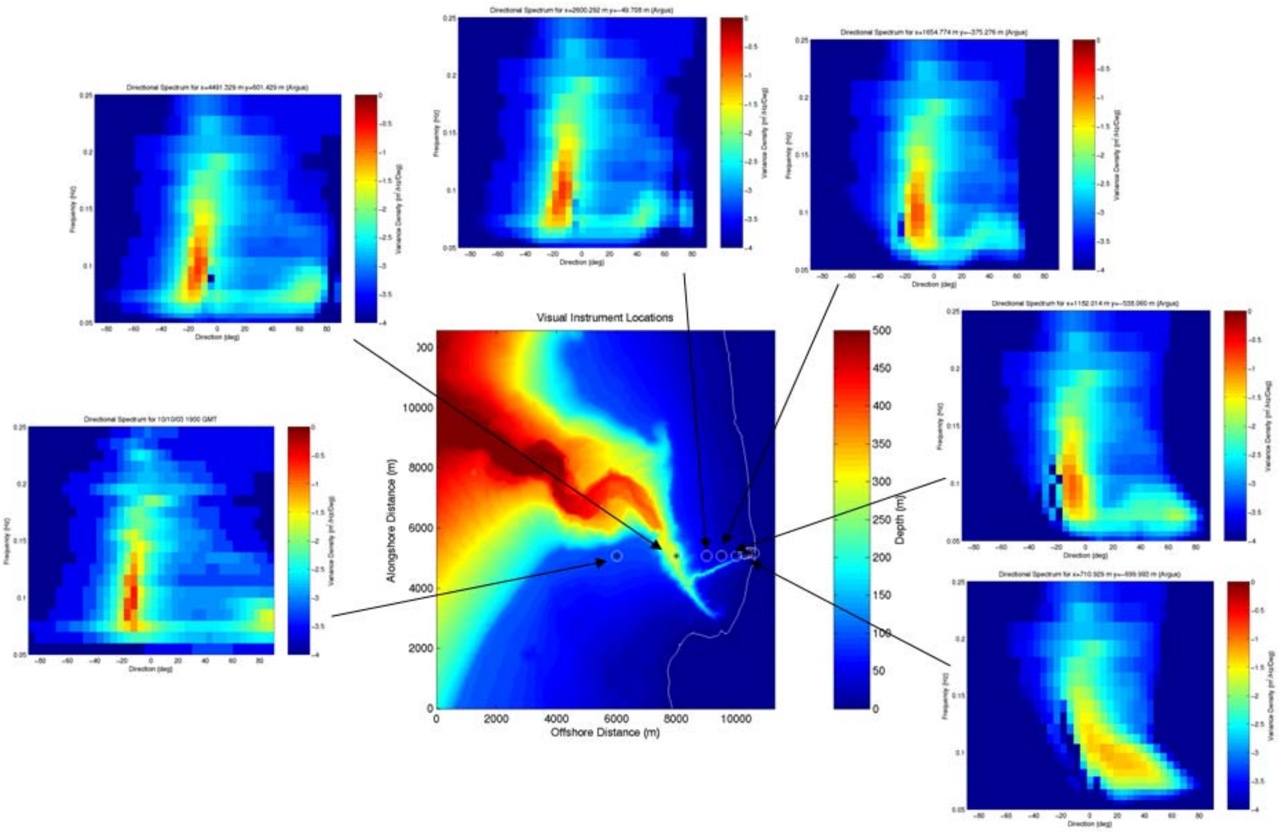

Figure 1: Frequency-directional spectra predictions for October 10, 2003 at NCEX. The measured offshore spectrum is displayed in the leftmost panel and consists of swell from the northwest along with longer period swell from the south. Contour plots of spectra depict energy density as a function of frequency (vertical axes) ranging from 0 to 0.25Hz and direction (horizontal axes) from -90° (corresponding to waves approaching from the north) to +90° (corresponding to waves approaching from the south).

Directional spectra 500m north of this cross-shore transect (not shown) are affected less dramatically since the wave rays from the northwest only cross the deepest portions of the canyon and do not experience the complicated features of the Scripps canyon. Therefore, north of Scripps canyon the waves continue to approach from the north causing a southward longshore current. Such converging longshore currents give rise to rip currents.

Wave height predictions derived from SWAN for October 10, 2003 are shown in Figure 2.The general trend is one that was anticipated: There are regions of large wave height to either side of the Scripps and La Jolla canyons and regions of low wave height immediately shoreward of the tips of the canyons. However, there are also smaller scale variations that are more pronounced than originally anticipated: The wave height varies between 1m and 2m over distances of O(100m), even in the existence of this relatively directionally broad wave field. It appears that these variations are related to undulations in the bathymetry contour along the edge of the canyon (see, for example, the 40m-contour). The undulations in the contours result in the deeper waters of the canyon to protrude out onto the shallower shelf in the form of “fingers”. The Blacks’ Beach area near the tip of the Scripps canyon

is shown in detail on the right panel of Figure 5. The color scale is indicative of wave height, the arrows indicate time-averaged (over 10mins) circulation predictions provided by a solution of the depth- and phase-averaged Navier Stokes equations (Özkan-Haller and Kirby, 1999). It is evident that the rip currents exist at the locations where the wave height is *locally* low, even in regions where the wave height is *generally* high (see y~1000m).

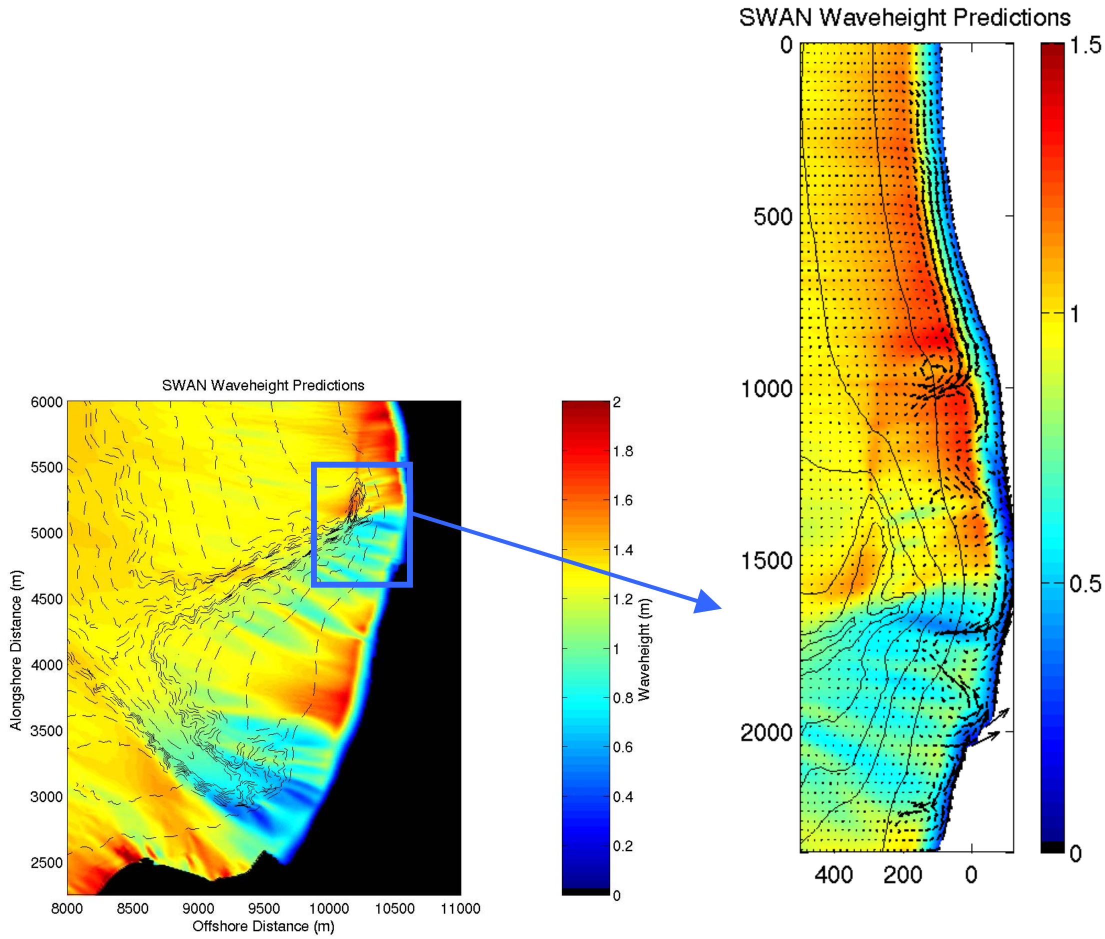

Figure 2: (left panel) Spatial variation of the predicted wave height (using SWAN). Note the focusing and defocusing patterns formed near the coast due to refraction over the undulating bathymetric features near the canyon walls. Dashed lines indicate contours every 10m. (right panel) the predicted mean circulation pattern near Blacks Beach overlayed on the wave height variation

Whether or not these predicted rip currents in fact existed can be assessed qualitatively with the help of Argus images. Figure 3 depicts the variance image for October 10, 2003 for the Blacks Beach area. Note that in this variance image brighter pixels are indicative of highly variable areas, such as the outer edge of the surf zone where wave breaking can be occasional. In Figure 3, we have also overlayed the computed 10-minute averaged circulation field for October 10 over the Argus variance image. The predicted rip currents correspond very closely to the observed rips. Comparisons with video-derived PIV velocities (Figure 3) indicate that the general magnitude of the currents is also predicted correctly, though differences exist because of the differences in the vertical level at which the velocities from the model and PIV are assessed. We are currently refining these comparisons.

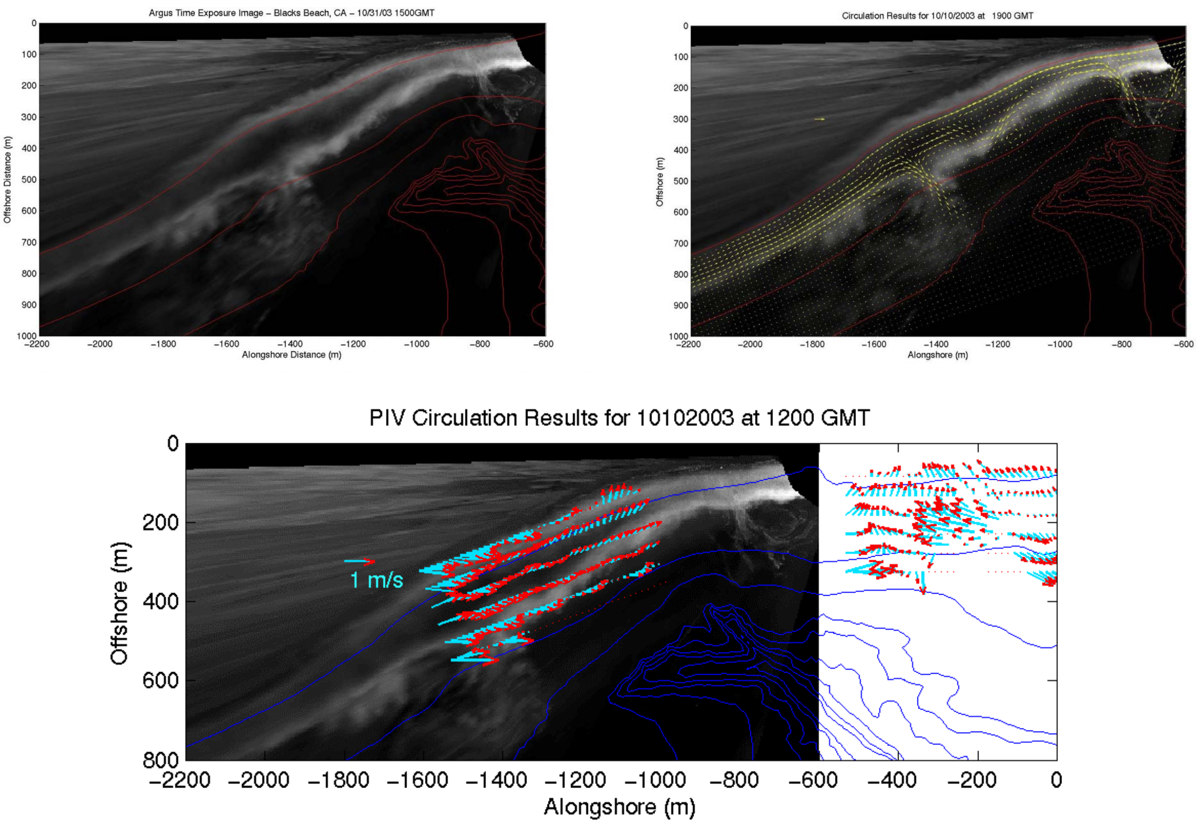

Figure 3: (upper left panel) Argus variance image for Oct 10, 2003 (upper right panel) Argus variance image with overlayed arrows indicating computed circulation pattern. A 1m/s vector is included in the upper left region of the image for scale. (lower panel) Video-based PIV estimates of time-averaged surface velocities.

IMPACT/APPLICATIONS

This study is furthering our understanding of the dynamics of waves and currents in the nearshore region. Also, we are enhancing our understanding of assimilation techniques and their application in the neashore region, particularly in relation to spatially non-uniform and possibly discontinuous data sets. The model development undertaken here will also pave the way to operational models for nowcasting and forecasting in the nearshore region.

TRANSITIONS

The work on the project will lead to a robust modeling tool which is capable of predicting the time-varying circulation field in the nearshore region. The model code developed herein will be available to the engineering and science communities. The resulting model can at a later date be transitioned to allow for operational use in hindcasting, nowcasting and ultimately forcasting circulation in the nearshore region. Alternately, the advances made herein can be incorporated into any such tool that the Navy may already be using.

RELATED PROJECTS

This effort is part of an overall program related to the Nearshore Canyon Experiment (NCEX) that took place off the coast of CA in the Fall of 2003. Close collaborations are planned with other researchers involved in NCEX-related projects. Also, knowledge gained about the skill of the modeling system developed herein will benefit the ongoing NOPP project (Lead P.I. J.T. Kirby) "Development and Verification of a Comprehensive Community Model for Physical Processes in the Nearshore Ocean".